Study of thermodynamic indices in association with pre-monsoon thunderstorms/Nor'westers over Northeast India during 2014-2018

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Abstract: The weather systems that predominantly affect the north-eastern parts of India during the pre-monsoon summer months (March-May) are severe thunderstorms, locally named as 'Kalbaishakhi' or 'Nor'westers'. The storms are devastating in nature particularly due to strong (gusty) winds, heavy rains and hails associated with it. Although these storms are well known for its power of causing damages, studies on them are relatively few due to their small size and sparse network of observations over the region.

In this paper an attempt has been made to analyse different stability indices like Showalter index, Lifted index , K index, Severe Weather Threat index, Total Totals index, Equivalent potential temperature at 850hPa level, Dew point temperature at 850hPa level, Relative humidity at 700hPa level, Humidity index and Deep Convective index in connection with occurrence of thunderstorm over three stations over North East India viz.,Agartala (23.88^{0}N, 91.25^{0}E), Dibrugarh(27.47° N, 94.91°E) and Guwahati (26.10^{0}N, 91.58^{0}E) for the year 2014, 2015, 2016 and 2017 during pre-monsoon summer months (March-May) using 0000 UTC radiosonde data to review and evaluate the atmospheric instabilities that may lead to thunderstorm development. Favourable ranges of these indices for occurrence of thunderstorms over the three selected stations of the region have been determined. Validation of the suggested favourable ranges of indices was also carried out on the days of thunderstorm activity for the year 2018.

Key words-Thunderstorm, index and favourable range

I. Introduction

In the tropics, most of the extreme weather events are convective in nature. Forecasters across the country routinely make subjective assessments of convective potential for their forecast area based on the values of various atmospheric parameters and indices in addition to synoptic features. Many parts over the Indian region experience thunderstorms at higher frequency during the pre-monsoon months (March–May), when the atmosphere is highly unstable because of high temperatures prevailing at lower levels. Thunderstorms are the manifestation of the convective activity in atmosphere which inflict huge damage to the life and property and cause severe socio-economic impact in the affected regions. As mentioned by Tyagi et al (2011) early forecasting of thunderstorm is essential in order to safeguard and prevent the damages resulting from these violent thunderstorms. During pre-monsoon season, the eastern and north-eastern (NE) parts of India, i.e. Assam, Odisha, Gangetic West Bengal, Jharkhand, Bihar and other parts of NE states, are affected by higher frequency of severe thunderstorms locally named as Kalbaishakhi or Nor'westers. These thunderstorms are predominantly from north-west(NW) direction and hence called as Nor'westers (Desai 1950; Kessler 1982). These Nor'westers are not local heat storms. The warm, moist, southerly

low-level flow from the Bay of Bengal and a cool, dry, westerly or NW upper-level flow existing over the region gives rise to a favourable synoptic setting for the formation of Nor'westers. Instability is a critical factor in the development of severe weather, and instability indices can be a useful tool when applied correctly to a given convective weather situation. Atmospheric instability is a critical factor in determining if thunderstorm development will commence.

Meteorologists use stability indices and skill scores to quickly asses the occurrence of the thunderstorms. Stability indices are a measure of the atmospheric static stability (Peppier 1988). Ravi et al. (1999) proposed two objective methods based on stability indices to forecast the occurrence of thunderstorms at Delhi. Mukhopadhyay et al. (2003) worked on objective forecast of thundery/non-thundery days using conventional indices over three NE Indian stations. Haklander and Delden (2003) reported the thunderstorm predictors and their forecast skill for the Netherlands. Kunz (2007) investigated the skill of convective parameters and indices to predict isolated and severe thunderstorms over southwest (SW) Germany. Dhawan et al. (2008) has suggested statistical techniques for forecasting pre-monsoon thunderstorms for NW India. Litta and Mohanty (2008) have used the few thermodynamic indices values given in the literature to identify the occurrence of thunderstorm activity in their modelling study of a thunderstorm event. Sa´nchezet al.(2008) studied the pre-convective conditions leading to thunderstorm activity over SW Argentina and developed a short-term forecast model.

The necessary conditions for development of thunderstorm are (i) Conditional instability, (ii) Low level convergence, (iii) Advection of moisture at the lower level(850hPa), (iv) Source of vertical lift of the parcel to trigger the convection and (v) Upper air divergence.

Sen and Basu (1961) have described the prevailing synoptic features over north east India during pre-monsoon months. The chief synoptic features are (i) A high pressure area south of 20^0N extending vertically up to middle troposphere and a low-pressure area north of 25^0N in the lower troposphere. (ii) Southerly/southwesterly wind at lower level up to 850hPa. (iii) The large scale flow in the upper atmosphere beyond 300hPa remains westerly. (iv) Eastward movement of western disturbance in the form of a low pressure area and/or trough in westerly passes over the region (v)The trough in westerlies often get extended up to Gangetic West Bengal causing incursion of moisture from Bay of Bengal.(vi) Low level circulation many times induces convection locally. (vii) The strong solar insolation and orographic lifting helps to from local convergence in this area (IMD,1944)

II. Data

The data of occurrence of thunderstorms during pre-monsoon season (March, April &May) for the year 2014-2018 of three stations viz., Guwahati, Agartala and Dibrugarh of north east India have been collected from the National Weather Forecasting Centre of India Meteorological Department, New Delhi. Thermodynamic indices are collected from Department of Atmospheric Science, University of Wyoming(http://weather.uwyo.edu/upperair/sounding.html). The data for the year 2018 used to validate the forecast skill of the indices for the three stations

III. GENERAL CLIMATOLOGICAL FEATURES OF THE STUDY AREA

The north eastern region of India consists of the states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, covering an area of 255168 km^2. These states consist of a part of the east Himalayan region, which extends from Arunachal Pradesh eastwards to the Darjeeling hills of West Bengal. The area is characterized by rich biodiversity, heavy precipitation and high seismicity. The climate is predominantly humid subtropical with hot, humid summers, severe monsoons and mild winters. Along with the west coast of India, this region has some of the Indian subcontinent's last remaining rain forests (Jain et al, 2012). Out of the total geographical area 28.3% has an elevation more than 1200 m, 17.9% between 600 and 1200 m and about 10.8% between 300 m and 600 m above mean sea level. The region has about 72% area under hilly ecosystems. The region has inaccessible terrain, fragility, marginality, excessive sloping land with rolling topography, rich biodiversity, unique ethnicity and socio-ecological set up. The North Eastern region received

high rainfall and therefore clothed with diverse and dense vegetation. Beyond the transitional pre-glacial region with increasing altitude, there appears the greater Himalayan region devoid of significant vegetative cover. Rocky surface, alpine vegetation and snowcapped high peaks dominate the physical landscape of this area. The altitudinal pattern of north east varies from place to place. The geographical location of three selected stations viz., Agartala, Dibrugarh and Guwahati has been shown in Fig.1

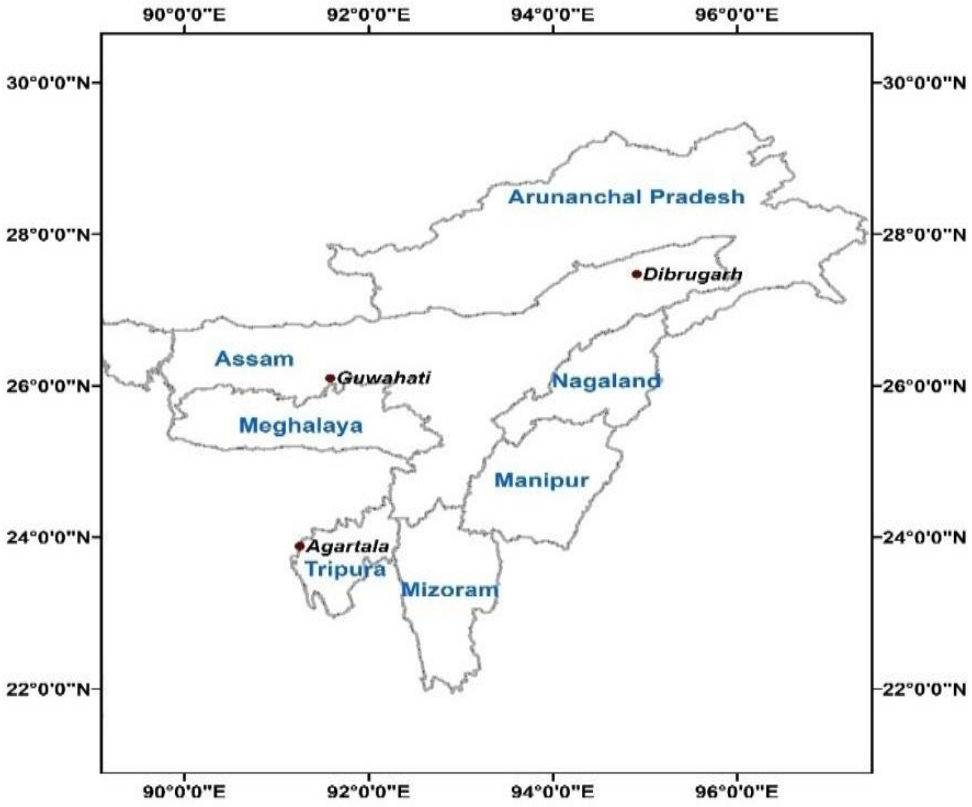


Fig.1 Geographical location of three selected station over map of North East India

IV. COMPUTATION OF INDICES

(i) Lifted Index (LI)

$LI = T_{500} - T_{parcel}$

Where T_{500} is the environmental temperature at 500hPa and T_{parcel} is the parcel temperature, it is lifted with the average temperature, pressure and dew point temperature from 500 m above the surface. It is a measure of thermal stability of the atmosphere at 500hPa and is expressed in terms of parcel temperature and environmental temperature (Means, 1952).

(ii) Showalter Index (SI) (Showalter, 1953)

$SI = T_{500} - T_{parcel}$

Where T_{500} is the temperature of environment at 500hPa and T_{parcel} is the 500hPa temperature which a parcel would attain if it is lifted dry-adiabatically from 850hPa to its condensation level and then moist-adiabatically to 500hPa level.

(iii) K Index (KI)

This index is used for determining the air mass thunderstorms. It is a combination of moisture at 850 and 700hPa level and temperature difference between 850 and 500hPa level (George, 1960)

$KI = (T_{850} - T_{500}) + Td_{850} - (T - Td)_{700}$

(iv)Total Totals Index (TTI)

This index is useful to assess the storm strength but fails to consider the latent instability below 850hPa (Miller, 1972)

$TTI = T_{850} + Td_{850} - 2\,T_{500}$

Where T and Td are the dry bulb and dew point temperatures at the indicated pressure levels.

(v) Severe Weather Threat Index(SWEAT)

This index is proposed by Miller (1972) for determining the severe weather

$SWEAT = 12\ Td_{850} + 20(TTI - 49) + 2f_{850} + f_{500} + 125[\sin(d_{500} - d_{850})] + 0.2$

Where f_{850}, f_{500} are the wind speed in knots at 850 and 500hPa level respectively and d_{500} , d_{850} are the wind direction in $0\text{-}360^0$ at 500 and 850hPa respectively.

(vi)Deep Convection Index (DCI)(K)

DCI is measure of lower-level temperature and 500hPa thermal instability (Barlow 1993).

$DCI(K) = T_{850} + Td_{850} - LI$

Where T and Td is the dry bulb and dew point temperature at 850hPa, and LI is the lifted index.

(vii)Humidity Index (HI)

This is a combination of the measure of saturation at 850, 700 and 500hPa (Litynska et al1976).

$HI(K) = (T - T_d)_{850} + (T - T_d)_{700} + (T - T_d)_{500}$

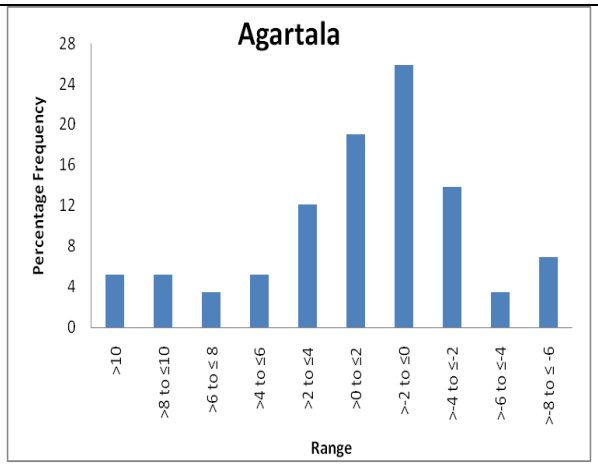
where T and T_d is the dry bulb and dew point temperature at 850,700 and 500hPa

V. RESULTS AND DISCUSSION

5.1 Showalter index

Fig.2(a-c) shows respectively the Showalter index over Agartala, Dibrugarh and Guwahati. From the figure it has been observed that during the period of study highest number of thunderstorms (25.9%) occurred over Agartala when Showalter index remains less than or equal to zero but greater than -2 followed by(19%) for the range 0 to +2. More than 70% thunderstorm occurred over Agartala during pre-monsoon season when Showalter index remained less than or equal to 4 but more than -4.

Over Dibrugarh highest number of thunderstorms (36.6%) occurred when Showalter index remains less than or equal to 2 but greater than 0 followed by(31%) in the range -2 to 0. About 83% of thunderstorms occurred over Dibrugarh during the pre-monsoon season when Showalter index remains less than or equal to 4 but more than -2. Whereas over Guwahati highest number of thunderstorms (30.8%) occurred when Showalter index remains less than or equal to 0 but greater than -2 followed by (19.7%) for both the ranges 0 to 2 and -4 to -2. About 81% of thunderstorms occurred over Guwahati during the premonsoon season when Showalter index remains less than or equal to 4 but more than -4.



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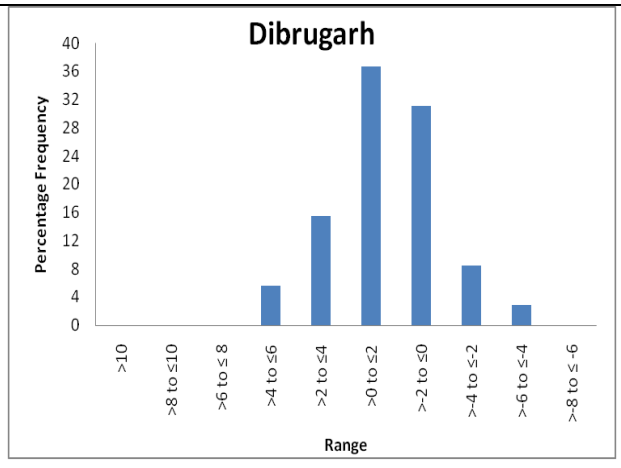

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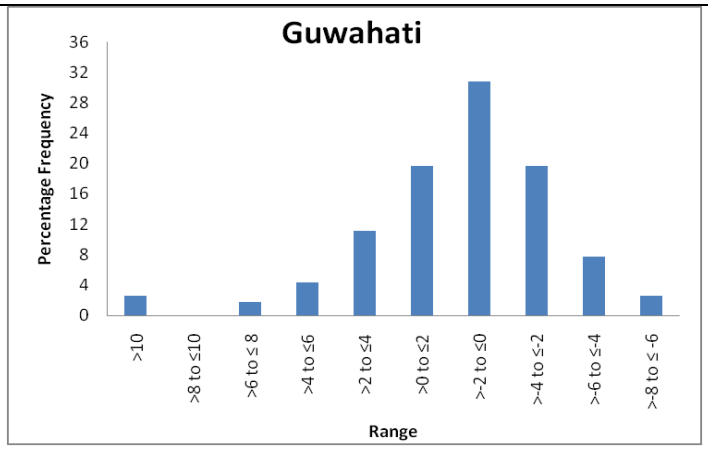


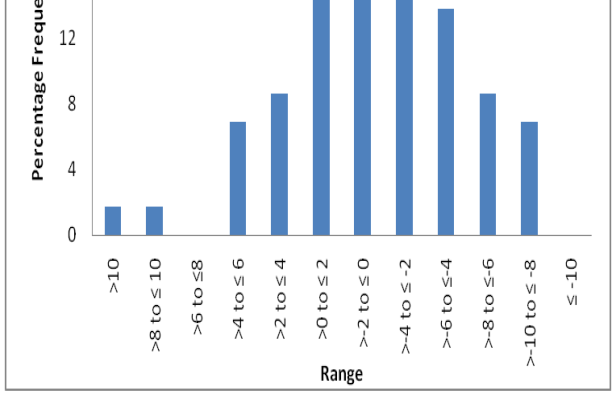
(c)

Fig.2 Percentage frequency of occurrence of thunderstorms in various ranges of Showalter index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

5.2 Lifted Index

Fig.3(a-c) represent the Lifted index over Agartala, Dibrugarh and Guwahati respectively. Analysis of Lifted index during the pre monsoon season over the three north eastern stations during the period of study reveals that the highest percentage frequency (19%) of thunderstorms occurred over Agartala for the ranges 0 to ≤ 2 followed by 17.2% for the range -2 to 0 whereas for Dibrugarh highest percentage frequency (34.2%) is for the range 0 to 2 followed by 23.7% for the ranges 2 to ≤ 4 and for Guwahati it is (36.7%) for the range -2 to ≤ 0 followed by 23.3% for the range 0 to ≤ 2.

About 66%, 90% and 74% of thunderstorm occurred for the ranges -6 to ≤ 2, -4 to ≤ 2 and -4 to ≤ 2 respectively over Agartala, Dibrugarh and Guwahati.



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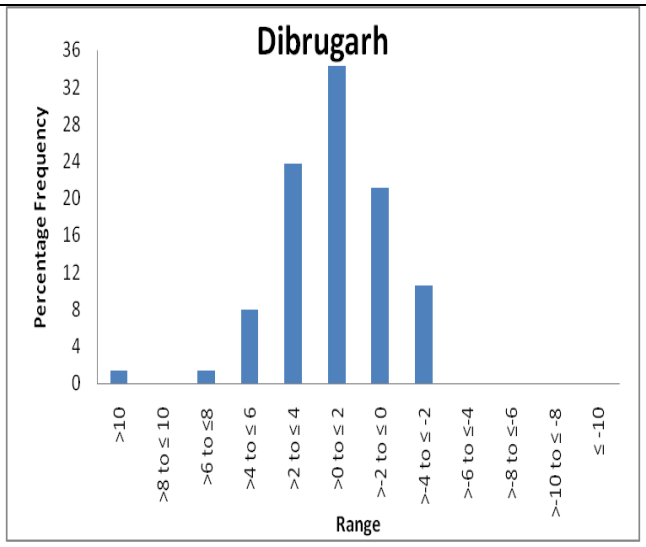

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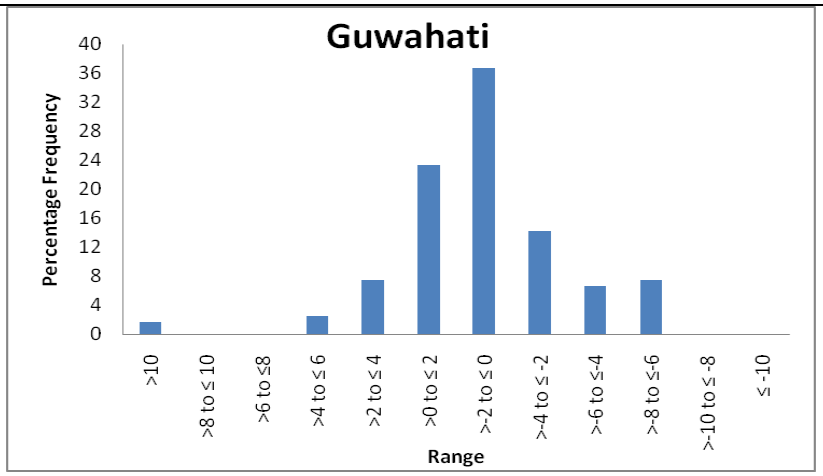


(c)

Fig.3 Percentage frequency of occurrence of thunderstorms in various ranges of Lifted index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

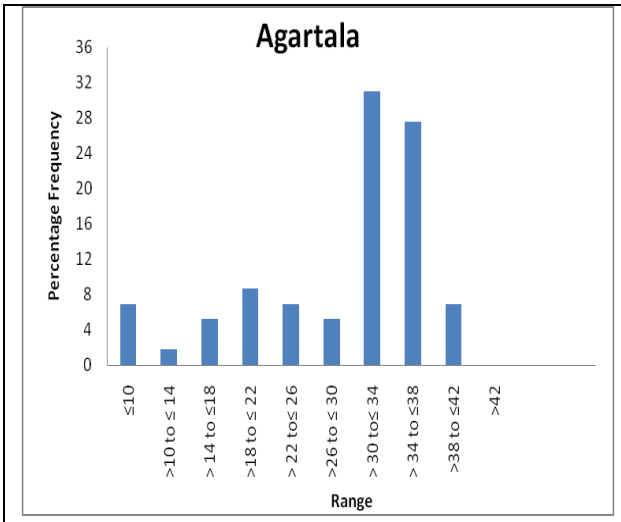
5.3 K-Index

The k-index is one of the main stability indices that is generally used to determine the probability of thunderstorm activity in an area.

The k-index over Agartala, Dibrugarh and Guwahati have been shown respectively in the Fig.4(a-c).

The study of k-index revealed that over Agartala the highest percentage frequency (31%) of thunderstorm occurred when the values of k lies between 30 to 34 followed by (27.6%) for the range 34 to 38, whereas for Dibrugarh and Guwahati the highest percentage frequency (49.3% and 37.9% respectively) observed when the values of k lies between 34 to 38 followed by 26.8% and 20.7% for the range 30 to 34 respectively.

The analysis of k-index over Agartala does not show any significant trend and found that about 59% of thunderstorm occurred when k-index lies between 30 to 38 whereas about 89% and 90% of thunderstorms occurred over Dibrugarh and Guwahati for the values of k between 30 to 42 and 26 to 42 respectively.



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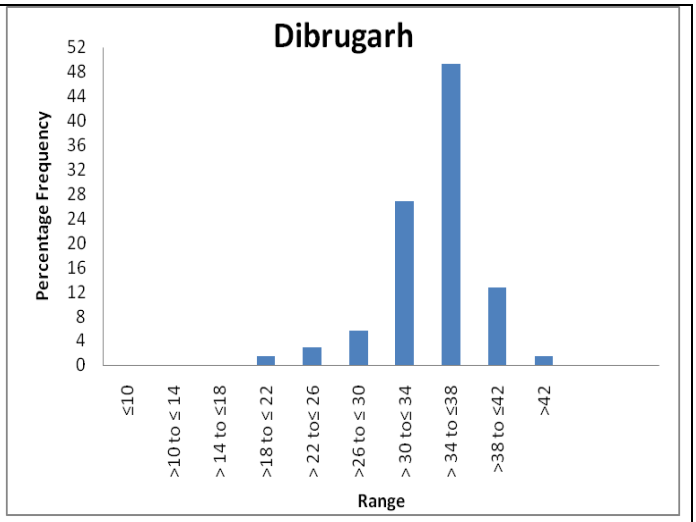

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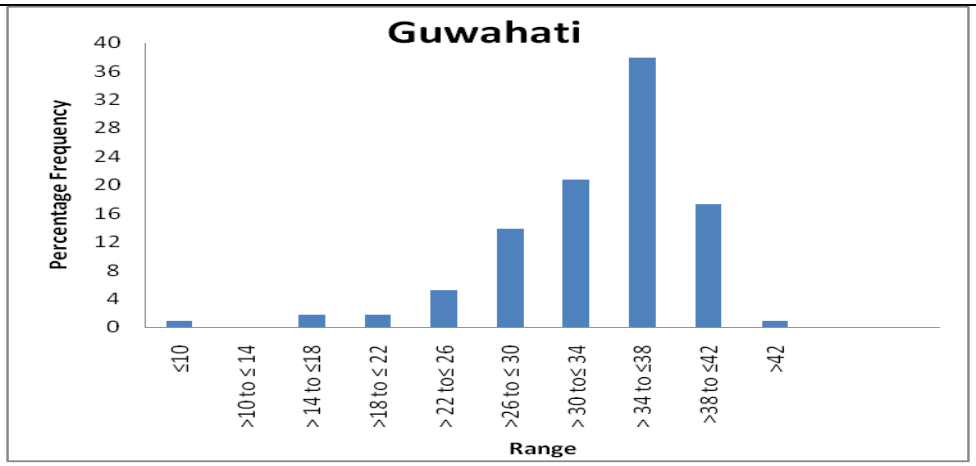


(c)

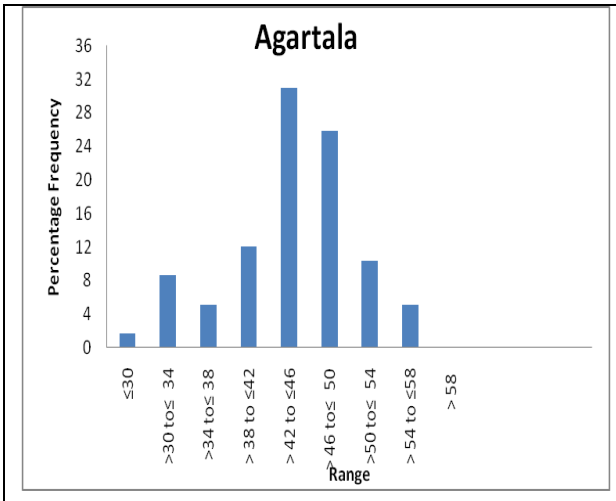
Fig.4 Percentage frequency of occurrence of thunderstorms in various ranges of K- index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

5.4 Total Totals Index

Total Totals index is actually a compound index designed to more accurately predict the occurrence of severe weather, in common practice the TT index is the more reliable single predictor of severe activity in both warm- and cold-air situations.

Fig.5(a-c) shows respectively the Total Totals index over Agartala, Dibrugarh and Guwahati.

When the values of TTI lies between 42 to 46 the percentage frequency of thunderstorm is found to be highest for all the three stations i.e. 31%, 54.9% and 36.8% respectively over Agartala, Dibrugarh and Guwahati respectively followed by 25.9%, 22.5% and 23.9% respectively over Agartala, Dibrugarh and Guwahati respectively. About 79% of thunderstorms occurred over Agartala for the ranges 38 to 54 of TTI whereas for Dibrugarh 90% and for Guwahati 78% of thunderstorm occurred for the ranges 38 to 50 and 42 to 54 respectively.



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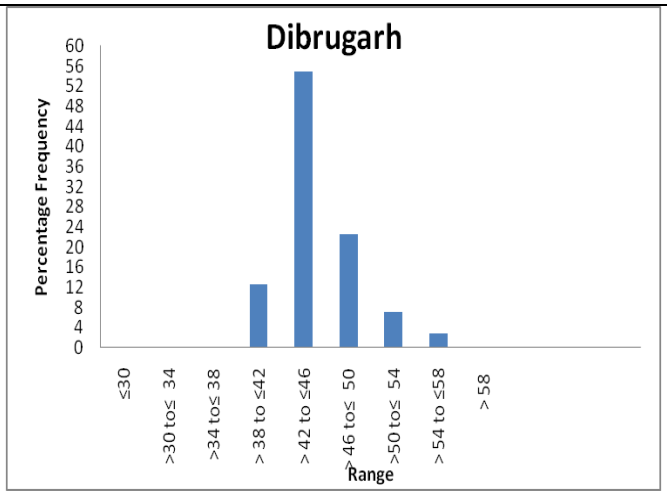

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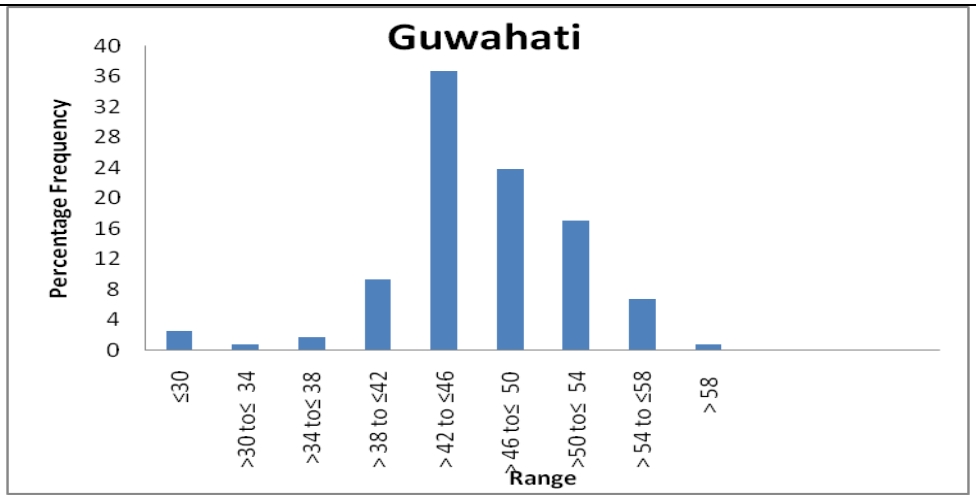


(c)

Fig.5 Percentage frequency of occurrence of thunderstorms in various ranges of Total Totals index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

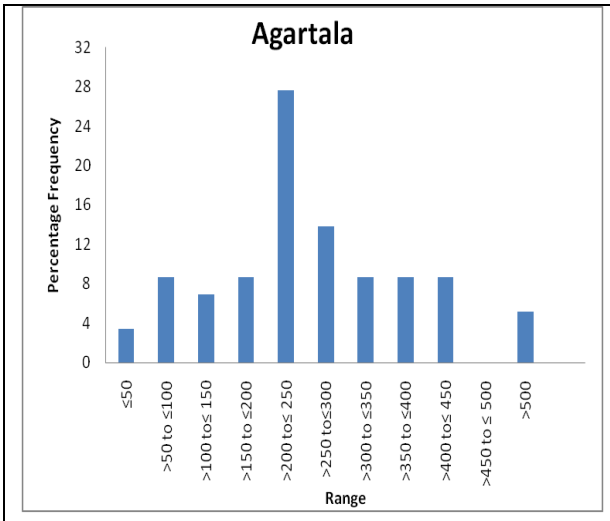
5.5 Severe Weather Threat index

The SWEAT Index evaluates the potential for severe weather by combining several parameters into one index. The SWEAT index indicates the potential for convection. There must still be sufficient forcing for upward motion to release the instability before thunderstorms can develop.

Fig.6(a-c) shows respectively the Severe Weather Threat (SWEAT) indexover Agartala, Dibrugarh and Guwahati.

The highest percentage frequency of thunderstorm has been observed over Agartala (27.6%) and Guwahati (29.8%) when the values of SWEAT index remains in between 200 to 250 followed by 13.8% over Agartala for the range 250 to 300 and 19.1% over Guwahati for the range 150 to 200 whereas over Dibrugarh the highest percentage frequency of thunderstorm (38%) has been observed for the range the 150 to 200 followed by 28.2% for the range 200 to 250.

About 76%, 76% and 81% thunderstorm occurred over Agartala, Dibrugarh and Guwahati when the ranges of SWEAT index lies respectively 150 to 450, 100 to 300 and 150 to 400.



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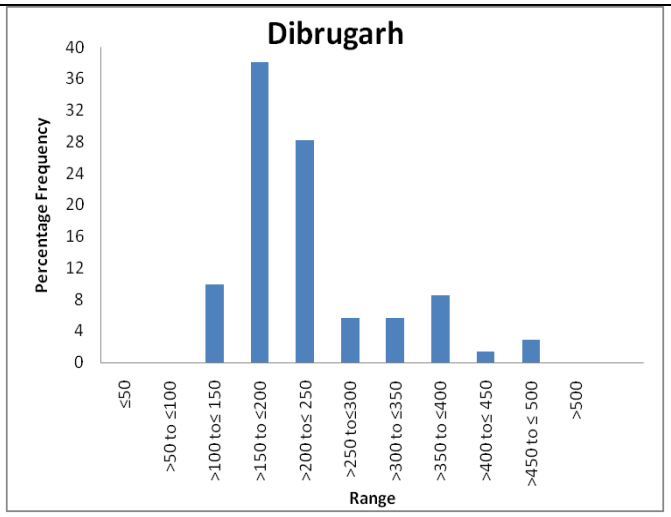

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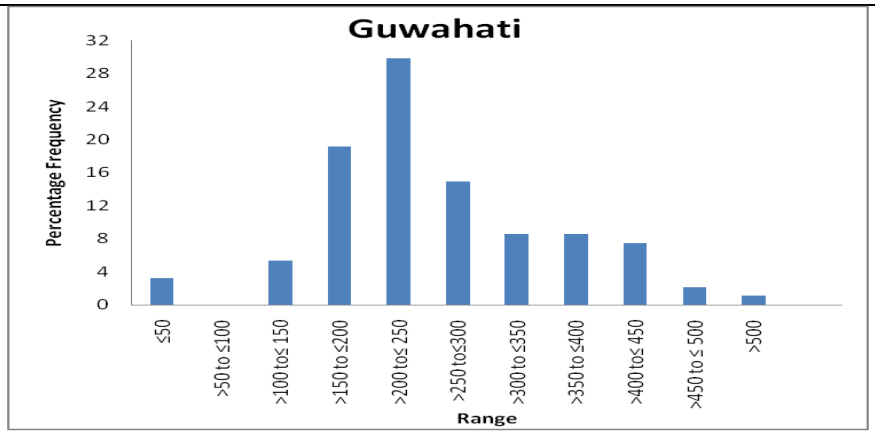


(c)

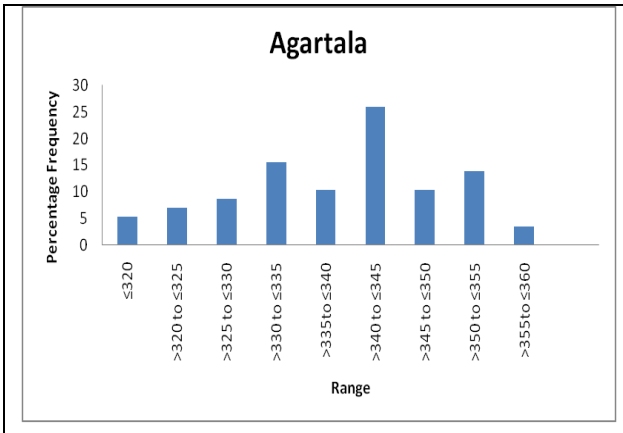
Fig.6 Percentage frequency of occurrence of thunderstorms in various ranges of SWEAT index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

5.6 Equivalent Potential Temperature at 850hPa level (θ_e)

The equivalent potential temperature is a useful quantity to assess moisture content, as well as thermal properties of the air column. θ_e is the final temperature that an air parcel would attain if lifted dry adiabatically to its lifting condensation level, then moist adiabatically until all water vapor, and finally brought down dry adiabatically to 1000hPa (Holton, 1972; Bolton, 1980; Bryan, 2008). θ_e relates to column moisture and to the potential release of latent heat.

Fig.7(a-c) shows Equivalent Potential Temperature at 850 hPa level over Agartala, Dibrugarh and Guwahati.

During the period of study highest number of thunderstorms (25.9%) occurred over Agartala when θ_e lies between 340 to 345 followed by 15.5% for the range 330 to 335. About 91% of thunderstorm occurred over Agartala during the pre-monsoon season when θ_e remains in between 320 to 355. Over Dibrugarh highest number of thunderstorms (43.4%) occurred when θ_e lies between 335 to 340 followed by 15.8% for the range 330 to 335. About 95% of thunderstorm occurred over Dibrugarh during the pre-monsoon season when θ_e remains in between 330 to 350. Whereas over Guwahati highest number of thunderstorms (25.7%) occurred when θ_e lies between 345 to 350 followed by (22.9%) for the range 340 to 345. About 86% of thunderstorm occurred over Guwahati during the pre-monsoon season when θ_e remains in between 325 to 350.



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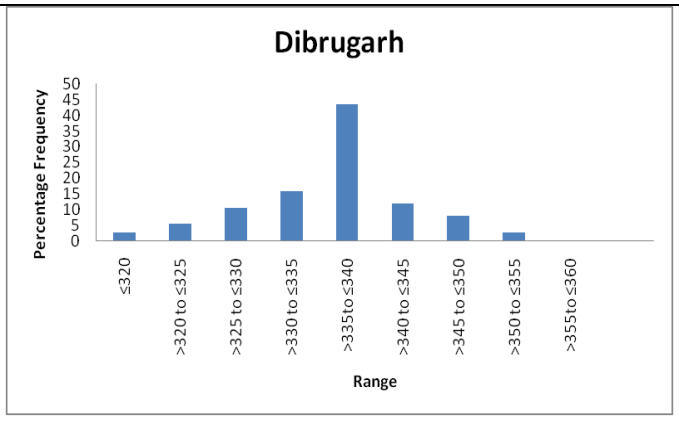

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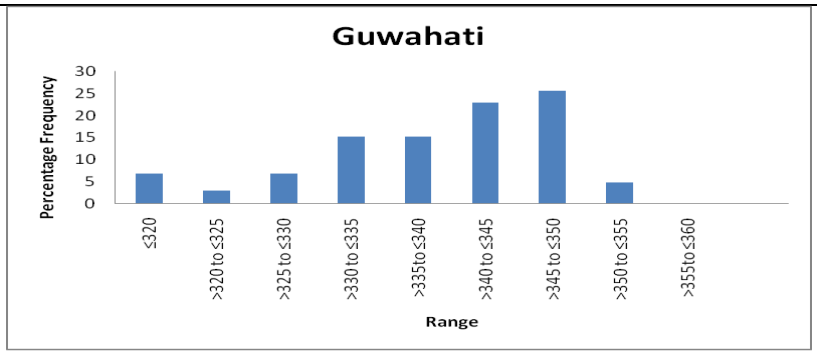


(c)

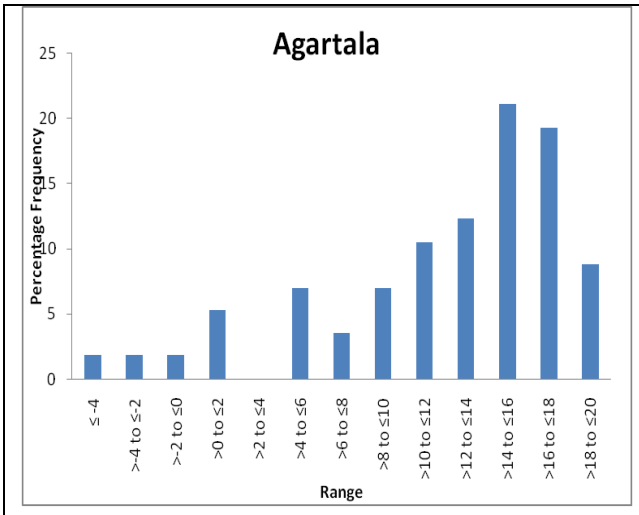
Fig.7 Percentage frequency of occurrence of thunderstorms in various ranges of Equivalent Potential Temperature at 850hPa level over (a) Agartala, (b) Dibrugarh and (c) Guwahati

5.7 Dew point Temperature at 850hPa level

The 850hPa level dew point temperature provides information on the moisture content of the lower atmosphere. The dew point Temperature at 850hPa level over Agartala, Dibrugarh and Guwahati is shown in the Fig.8 (a-c).

Analysis of dew point temperature at 850hPa level shows that for both Agartala and Guwahati the highest percentage frequency have been observed as 21.1% and 28.7% respectively for the ranges 14 to 16 followed by 19.3% and 20.8% respectively for the range 16 to 18 whereas for Dibrugarh the range of dew point temperature is 12 to 14 for which the percentage frequency of thunderstorm is highest(36.8%) followed by 19.7% for the range 14 to 16.

The analysis further revealed that about 79% thunderstorm over Agartala, 96% over Dibrugarh and 88% over Guwahati occurred for the ranges 8 to 20, 6 to 18 and 8 to 18 respectively.



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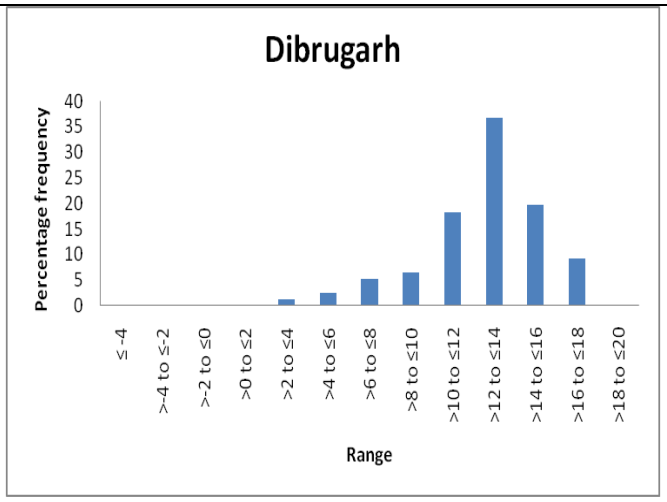

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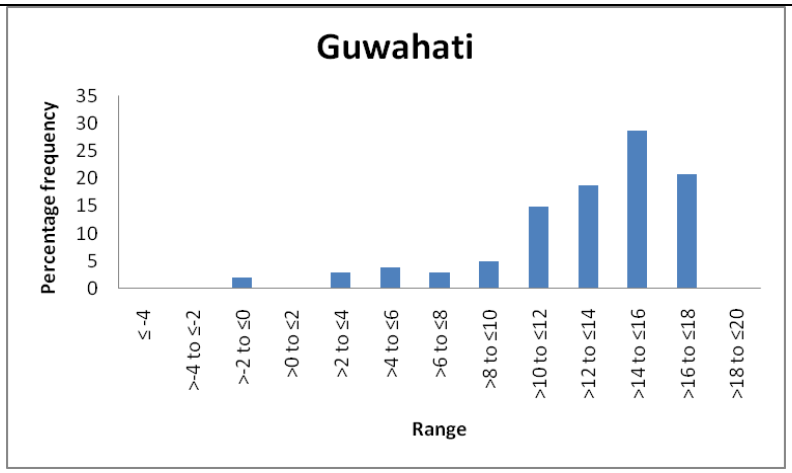

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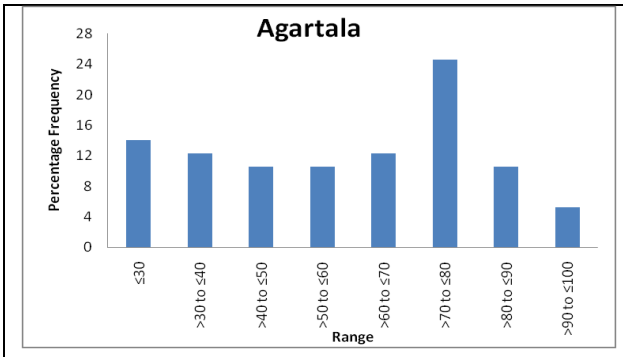
Fig.8 Percentage frequency of occurrence of thunderstorms in various ranges of Dew Point Temperature at 850hPa level over (a) Agartala ,(b) Dibrugarh and (c) Guwahati

5.8 Relative humidity at 700hPa level

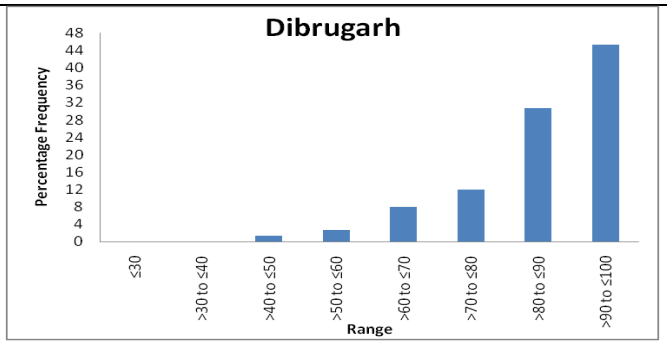
According to Gibbs and Butts Jr (2015) there appears to be a link between middle and lower level moisture content (specifically at 850–700hPa) and the frequency of thunderstorm development, with little variability in many other meteorological variables. Higher 850–700hPa relative humidity values link to much higher rates of thunderstorm development. The Relative humidity at 700hPa level over Agartala, Dibrugarh and Guwahati is shown in the Fig.9(a-c).

The analysis of 700hPa level relative humidity shows that during the period of study the relative humidity at 700hPa level over Agartala does not show any significant trend as considerable number of thunderstorm occurred even when the relative humidity at 700hPa level remains less than or equal to 30% and only about 40% of thunderstorm occurred when the relative humidity remains greater than 70%. The highest percentage frequency of thunderstorm (24.6%) found for the range of relative humidity greater than 70% and less than or equal to 80%.

Over Dibrugarh the highest percentage frequency (45.3%) of thunderstorms found for the range 90 to 100% of relative humidity followed by30.7% for the range 80 to 90%. Over Guwahati the highest percentage frequency (28.3%) of thunderstorm occurred for the range 70 to 80% followed by 26.7% for the range 80 to 90%. About 88% of thunderstorm occurred over Dibrugarh when the relative humidity has been observed above 70% and over Guwahati about 68% of thunderstorm occurred when the relative humidity remains above 70%.



(a)



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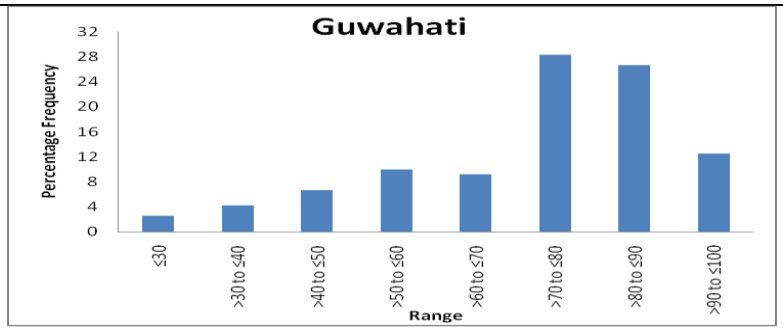


(c)

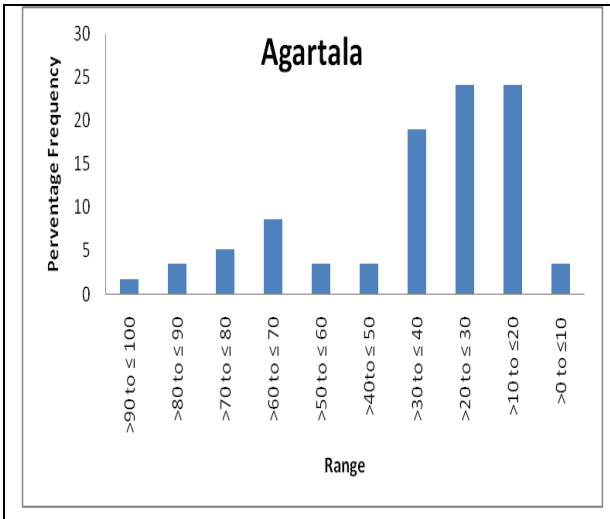
Fig.9 Percentage frequency of occurrence of thunderstorms in various ranges of Relative humidity at 700hPa level over (a) Agartala, (b) Dibrugarh and (c) Guwahati

5.9 Humidity Index (HI)

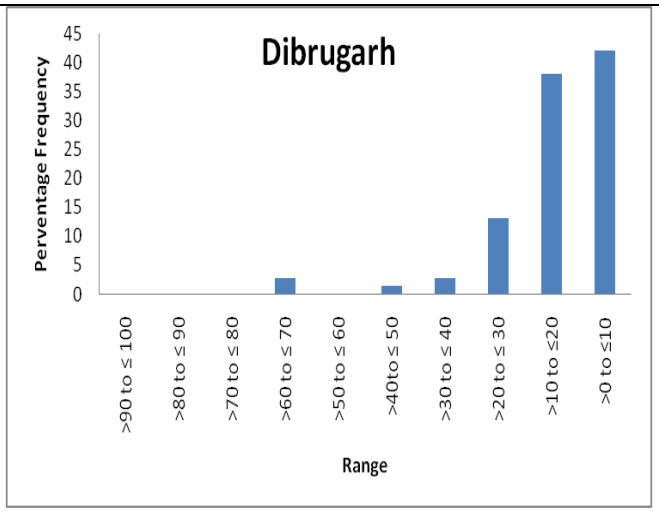
HI value shows the available moisture in the atmosphere and is the main index for the development of thunderstorm. The HI over Agartala, Dibrugarh and Guwahati is shown in the Fig.10 (a-c).

Analysis of HI over Agartala shows that percentage frequency of thunderstorm is maximum for both the ranges 20-30 and 10-20 followed by the range 30-40. Over Dibrugarh the percentage frequency is highest (42.1%) when the Humidity index remains less than or equal to 10 followed by the range 10-20 and over Guwahati the percentage frequency is highest (39%) when the Humidity index remains less than or equal to 20 but greater than 10 followed by the range 0 to 10.

Over Agartala about 67% of the thunderstorm occurred when the value of Humidity index remains less than or equal to 40 but greater than 10. Over Dibrugarh about 93% of thunderstorm occurred when the value of Humidity index found to be less than or equal to 30 whereas over Guwahati about 95% of thunderstorm occurred when the value of Humidity index remains less than or equal to 50.



(a)



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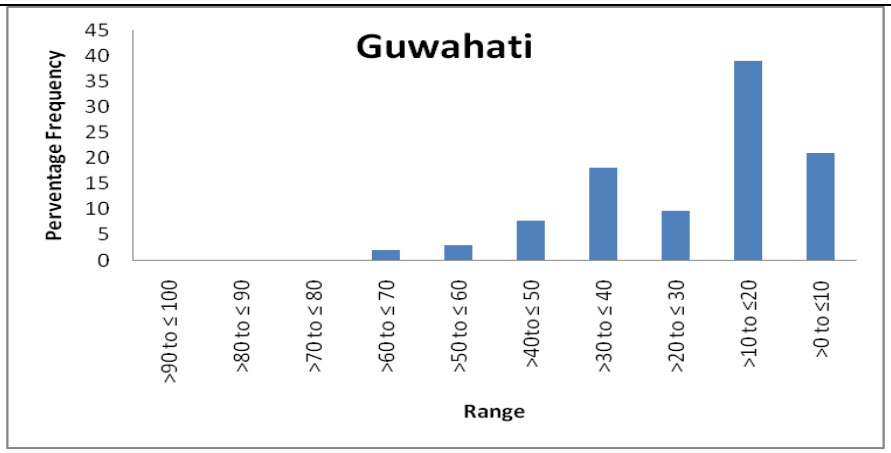


(c)

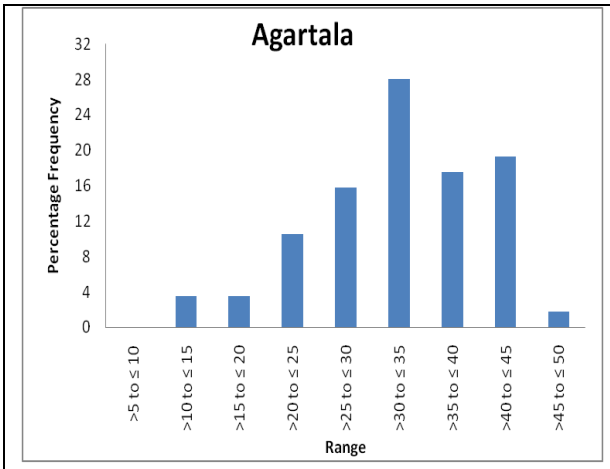
Fig.10Percentage frequency of occurrence of thunderstorms in various ranges of Humidity index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

5.10 Deep Convective Index (DCI)

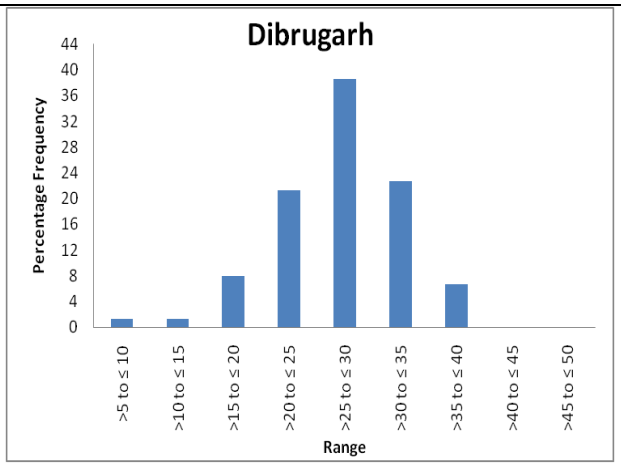
DCI is measure of lower-level temperature and 500hPa thermal instability (Barlow 1993).The DCI attempts to combine the properties of equivalent potential temperature at 850hPa with instability.The DCI over Agartala, Dibrugarh and Guwahati is shown in the Fig.11 (a-c) .

Analysis of Deep Convective index over the three stations revealed that over Agartala the highest percentage frequency (28.1%) of thunderstorm occurred for the ranges 30 to 35 of DCI followed by 40 to 45, over Dibrugarh the highest percentage frequency (38.7%) occurred for the ranges 25 to 30 followed by the range 30 to 35 and over Guwahati it is (32.7%) for the range 30 to 35 followed by 35 to 40.

Over Agartala about 91% of thunderstorm occurred for DCI value more than 20 but less than or equal to 45, over Dibrugarh about 97% of thunderstorm occurred when the value of DCI found to be greater than 15 but less than or equal to 40 and over Guwahati about 92% of thunderstorm occurred when the value of DCI remains greater than 20 but less than or equal to 45.



(a)



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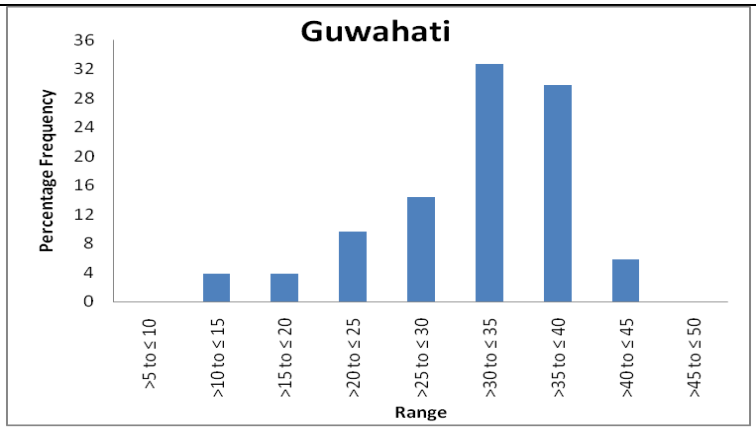

(c)

Fig.11 Percentage frequency of occurrence of thunderstorms in various ranges of Deep Convective index over (a) Agartala, (b) Dibrugarh and (c) Guwahati

VI. FAVOURABLE RANGES OF INDICES

In order to fix the favourable range for an index we have considered all the ranges of index in which percentage frequency of occurrence of thunderstorm is more than 10% continuously. The lower limit of all such ranges and the upper limit have been considered as the favourable range of the index. In this way we have calculated the favourable ranges for all the three stations separately. The indices with their favourable ranges are shown in Table-1

Indices	Critical Value		
	Agartala	Dibrugarh	Guwahati
Showalter index	>- 4 to ≤4	>- 2 to ≤4	>- 4 to ≤4
Lifted index	>- 6 to ≤2	>- 4 to ≤4	>- 4to ≤2
K index	>30 to ≤38	>30 to ≤42	>26 to ≤42
TTI	>38 to ≤54	>38 to ≤50	>42 to ≤54
SWEAT Index	>200 to ≤300	>150 to ≤250	>150 to ≤300
Eq. Pot. temp. (°K) (850 hPa level)	>330 to ≤355	>325 to ≤345	>330 to ≤350
Dew point Temp. (°C) (850 hPa level)	>10 to ≤18	>10to ≤16	>10 to ≤18
Rel. Humidity (700 hPa level)	>70%	>70%	>70%
Humidity Index	>10 to ≤40	≤30	≤40
Deep Convective Index	>20 to ≤45	>20 to ≤35	>25 to ≤40

Table-1 Favourable ranges of the selected indices

VII . VALIDATION OF FAVORABLE RANGES FOR THE YEAR 2018

The skill of indices in association with the occurrence of thunderstorms over the selected three stations has been shown in Table-2.

From Table-2 it has been observed that over Agartala out of selected ten indices four indices viz., Showalter index, Total Totals index, Equivalent potential temperature at 850hPa level and Deep Convective index are found to be within the favourable ranges for more than 80% cases. It has also been observed that the performance of k-index, SWEAT index and

Relative humidity at 700hPa is not so encouraging as about 50% of thunderstorms occurred when these indices remained within the favourable range.

Table-2 Performance of indices in association with the occurrence of thunderstorms over

Indices	Percentage Frequency of TS		
	Agartala	Dibrugarh	Guwahati
Showalter Index	89	73	95
Lifted Index	77	100	85
K-index	54	91	98
TTI	94	100	83
SWEAT Index	40	70	83
Eq.Pot.Temp.850hPa	91	64	71
Dew Pt.Temp 850hPa	77	55	81
RH 700hPa	49	100	63
HI	71	91	83
DCI	97	64	81

Over Dibrugarh five indices viz., Lifted index, k-index, Total Totals index, Relative humidity at 700hPa and Humidity index remained within the favourable range for more than 80% cases. It is also observed that the indices Lifted index, Total Totals index and Relative humidity at 700hPa were within the favourable ranges for all the days of thunderstorm over Dibrugarh during the year 2018. Analysis also revealed that for only about 55% number of cases of occurrence of thunderstorm dew point temperature at 850hPa level found to be within the favourable range.

Over Guwahati eight indices out of selected ten indices viz., Showalter index, Lifted index, K index, Severe Weather Threat index, Total Totals index, Dew point temperature at 850hPa level, Humidity index and Deep Convective index remains within the favourable range for more than 80% cases of thunderstorm. Only about 63% of thunderstorm days the Relative humidity at 700hPa level remains within the favourable range which is lowest amongst all the indices.

Table-3 represents number of indices together that remain within the favourable range for each thunderstorm days. From the table it has been observed that over Agartala corresponding to highest percentage frequency of thunderstorm (23%) seven indices remained within the favourable range followed by nine indices corresponding to 20% of thunderstorm days.

No. of indices satisfying favourable ranges	Agartala	Dibrugarh	Guwahati
	Percentage frequency	Percentage frequency	Percentage frequency
10	14	46	32

9	20	9	34
8	14	9	10
7	23	0	2
6	9	27	10
5	9	0	5
4	8	9	2
3	0	0	5
2	3	0	0

Table-3 Number of indices together satisfying the favourable ranges for each thunderstorm days.

Over Dibrugarh corresponding to highest percentage frequency of thunderstorm (46%) all the selected ten indices remained within the favourable range followed by six indices corresponding to 27% of thunderstorm days and over Guwahati corresponding to highest percentage frequency of thunderstorm (34%) nine indices remained within the favourable range followed by all the selected ten indices corresponding to 32% of thunderstorm days.

VIII. CONCLUSIONS

It is found that one index alone cannot predict the occurrence of thunderstorm over the selected stations and at the same time even some indices have values less than/greater than that of favourable range; there may be a thunderstorm over the stations.

From the study it has been observed that almost all the ten indices considered for this study show significant trend over Dibrugarh and Guwahati but did not show any significant trend over Agartala.

In general, the proposed ranges of the indices in the study are performing reasonably well in identifying the occurrence of thunderstorm with reference to available observations. There are possibilities that even values of various indices are lower than threshold limits, there may be a thunderstorm on that day.

Among the ten selected indices Showalter index, Total Totals index, Equivalent potential temperature at 850hPa level and Deep Convective index over Agartala and Lifted index, k-index, Total Totals index, Relative humidity at 700hPa and Humidity index over Dibrugarh and also over Guwahati Showalter index, Lifted index , k index, Severe Weather Threat index, Total Totals index, Dew point temperature at 850hPa level, Humidity index and Deep Convective index appears to be best predictors of thunderstorm.

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